# Level-0 Calorimeter and L1 Global Triggers WBS 6.8.y.1 and 6.8.y.3

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U.S. ATLAS HL-LHC Upgrade NSF Conceptual Design Review

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# Outline

- **System experts and Principle Investigators**
- **System Overview**
  - Current (Run-2) System, Phase-1 upgrade and Motivation for Upgrade
  - ATLAS Upgrade Plans
- **Proposed U.S. HL-LHC Upgrade Scope**
  - Work Breakdown Structure and Contributing Institutes
  - U.S. Deliverables
- **Ongoing R&D**
  - Plans to Construction Project
  - Funding Needed
- **Construction Project Management**
  - Construction Project Budget and Schedule
  - Risks and Mitigation
- **Closing Remarks**

# About the Expert

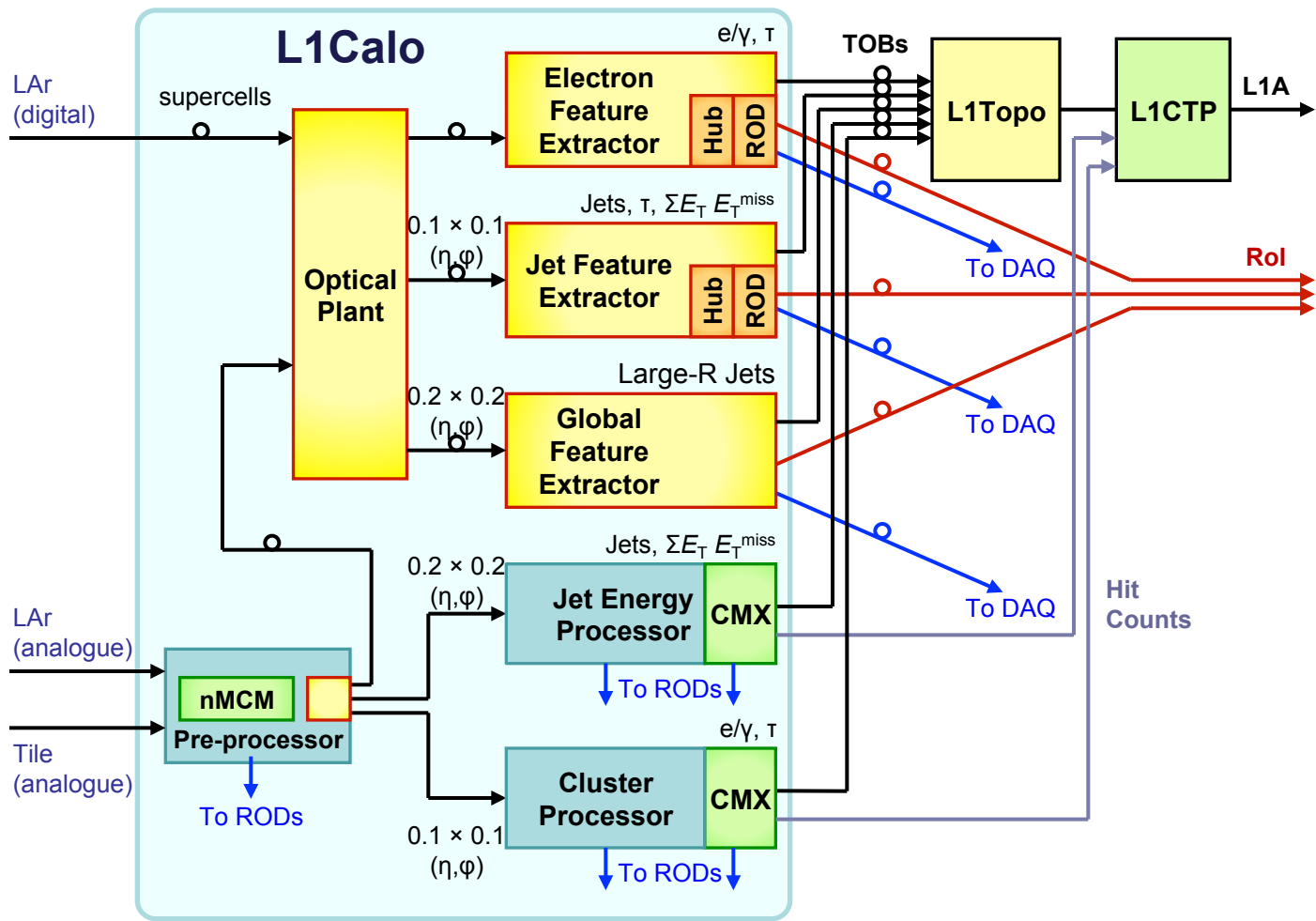- ## Wade Fisher, Associate Professor, Michigan State University
    - Member of ATLAS collaboration and TDAQ group since 2012
    - L3 manager for Phase 1 upgrade project: FEX ATCA Hub module
    - MSU also built and commissioned Phase 0 upgrade L1Calo module: Common Merger Module Extended (CMX)
        - MSU Engineers Dan Edmunds, Philippe Laurens, Yuri Ermoline, Pawel Plucinski

- ## Additional Primary Contributions
    - Sizable list of TDAQ experts with significant upgrade experience have contributed to this project proposal
    - L0 Calo: Reinhard Schwienhorst (MSU), Hal Evans (Indiana)
    - L1 Global: WF (MSU), Stephanie Majewski (Oregon), Elliot Lipeles (Penn)
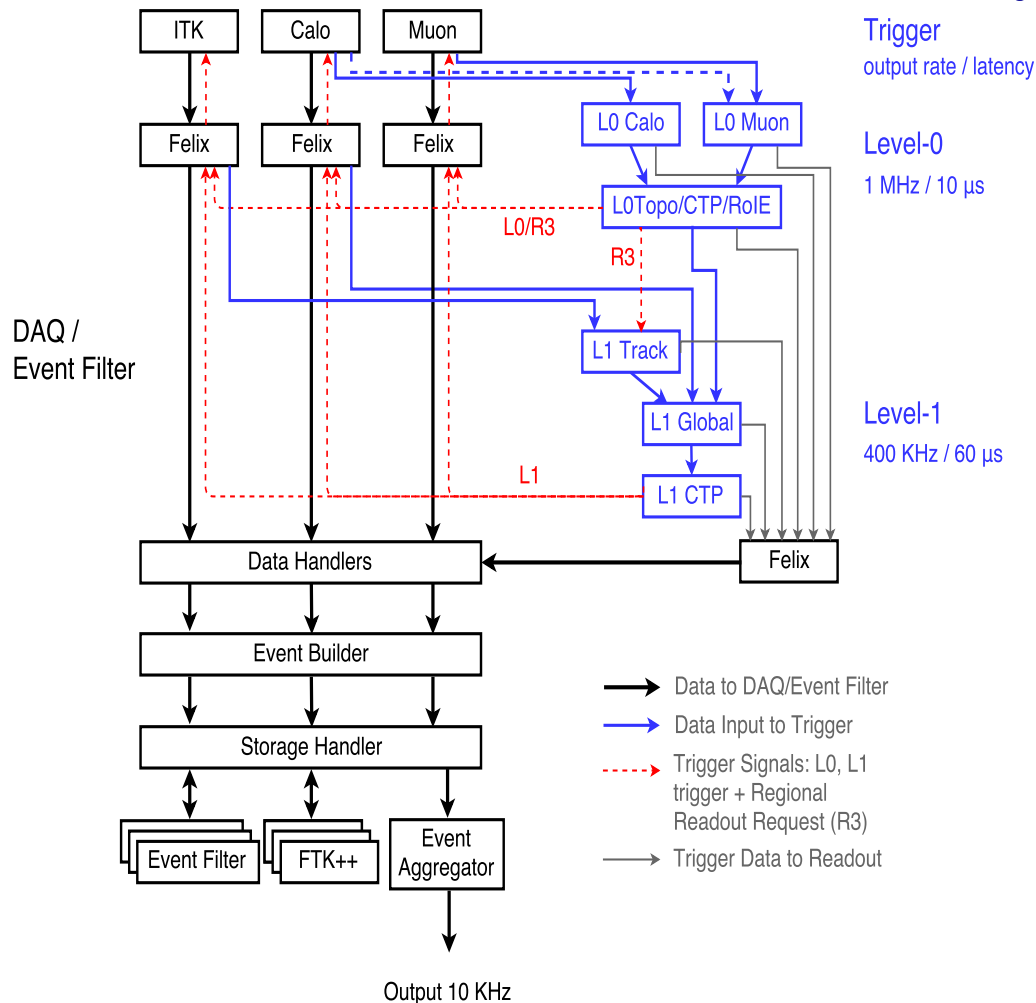
# About the Institutes

- Institutes involved
  - Michigan State University
  - University of Chicago
  - Indiana University
  - University of Oregon
  - Louisiana Tech University
  - University of Pittsburg
- Extensive history of HEP construction effort for all institutes
  - TDAQ: MSU, Indiana, Chicago
  - TRT: Indiana
  - Muons: Pitt,
  - TileCal: Chicago, MSU
  - LAr: Pitt,
  - FTK: Chicago
  - Nearly all groups have non-ATLAS construction experience

# Phase 1 Upgrade Overview

- ## Two-level hardware system
  - Phase-1 L1 system becomes HL-LHC L0 system
  - High precision Muons (MDT) added to L0 system → improves efficiency
  - L0 Rate is now 1 MHz
    - Allows in more physics
  - L1 system uses tracks and full granularity calo in regions of interest to improve reject before HLT
    - Tracking 10% of data at 1 MHz
  - Full detector tracking for 100 KHz events in HLT → mitigates pile-up for hadronic triggers
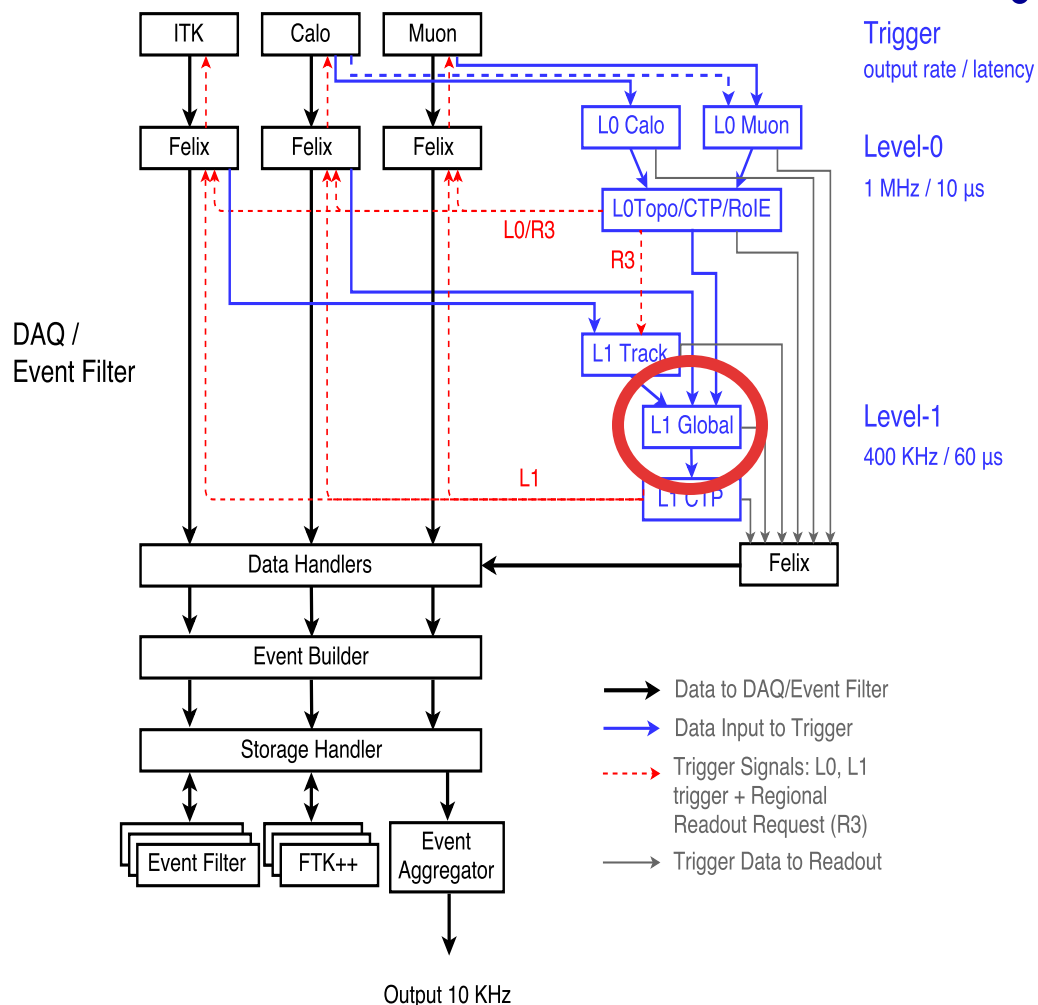
# HL-LHC System Upgrade Plans
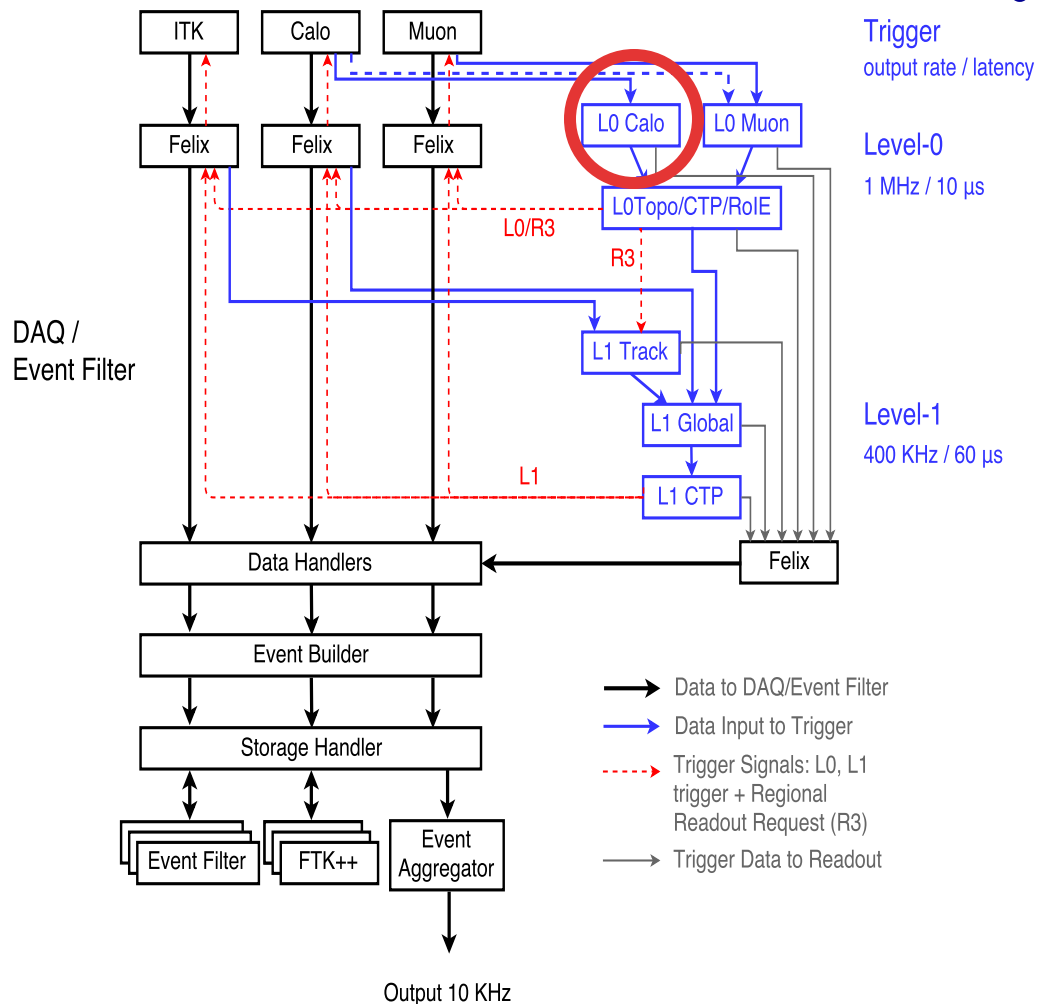


- ## Level-0 Calorimeter Trigger

  - Phase-1 L1 system becomes HL-LHC L0 system

  - Tile input to L0Calo will be new digital input from Tile preprocessor

  - New Tile Optical Plant needed for new Tile front-end electronics mapping / interface

    - Builds on existing optical plant experience and design.

ITK | Calo | Muon

**Trigger**
output rate / latency

L0 Calo | L0 Muon

**Level-0**
1 MHz / 10 μs

L0Topo/CTP/RoIE

L0/R3

R3

L1 Track

L1 Global

**Level-1**
400 KHz / 60 μs

L1

L1 CTP

Felix

Data Handlers

Event Builder

Storage Handler

DAQ / Event Filter

Event Filter | FTK++ | Event Aggregator

Output 10 KHz

→ Data to DAQ/Event Filter
→ Data Input to Trigger
⇢ Trigger Signals: L0, L1 trigger + Regional Readout Request (R3)
→ Trigger Data to Readout

- **Level-1 Global Trigger**
  - L1 Global system aggregates inputs from Calo, Muon and Track triggers
  - Processes fine-granularity calorimeter inputs for improved siganatures
  - Evaluates combined trigger algorithms using 'global' information
  - Proposed NSF scope focuses on current US hadronic trigger experience to support processor algorithm design
    - Energy clustering and jet identification
    - Global calorimeter quantities (MET, HT)
    - Track-based pileup rejection

# Proposed NSF Scope

- ## 6.8.y.1 L0 Calo Optical Plant
  - Rebuild fiber optic input router because of changes to tile inputs
  - MSU is building Phase-1 system this capitalizes on their unique expertise
  - **Institutes**: Michigan State (MSU)

- ## 6.8.y.3 L1 Global Processing
  - L1 Global algorithms are where the rate reduction from 1 MHz to 400 KHz happens
  - 4 firmware algorithms focused on hadronic triggering:
    - Offline-like energy clustering and jet construction, global quantities (MET, HT), and track-based pile-up rejection
  - This builds on US experience with Phase-1 "gFEX" system which does global hadronic triggering in what will be L0
  - **Institutes**: U Chicago, Indiana U., Louisiana Tech, Michigan State, U Oregon, U Pittsburgh

# 6.8.y.1: L0 Calo Fiber Optic Plant

- Rebuild the Phase 1 Fiber Optic plant to accommodate the change to the tile electronics

- Builds on unique MSU experience with fiber routing and splitting

Tile inputs changes

So routing needs to change
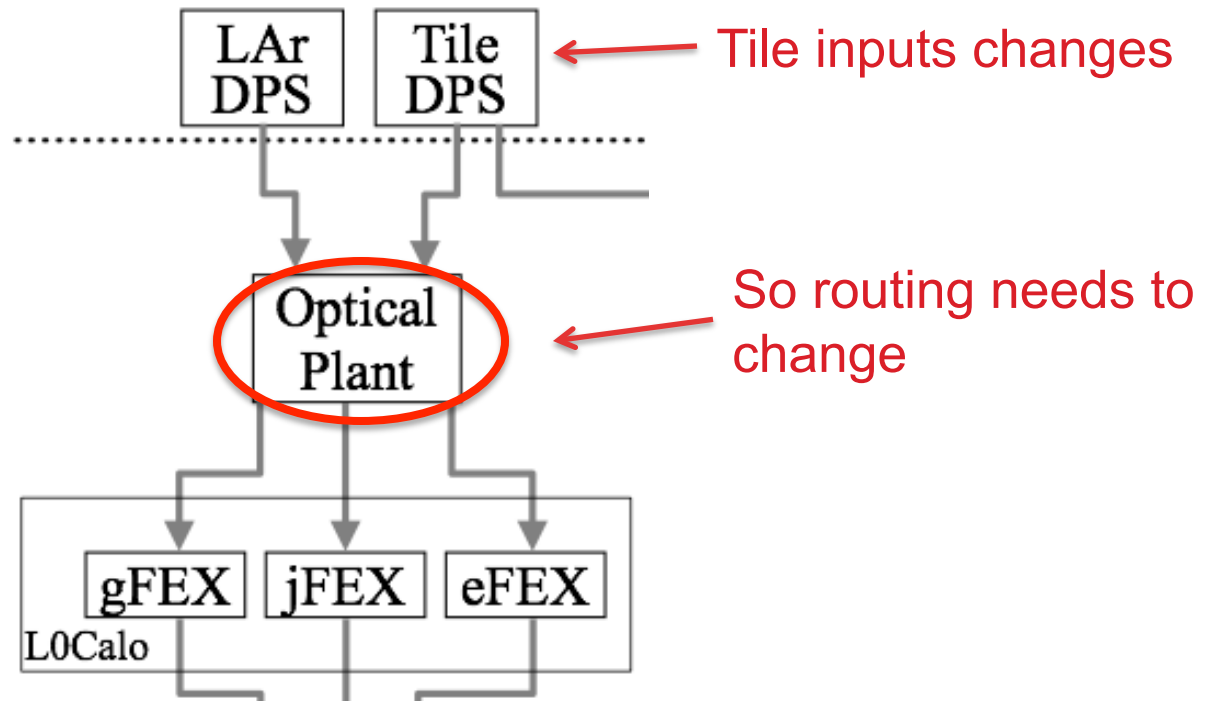
- ## Phase 1 Deliverable: Fiber-Optic eXchange (FOX)

  - Project underway at MSU
  - Well-understood technical challenges

optical plant

| EM calo. | LAr supercells | LArFox | eFox | LAr supercells | eFEX |
|---|---|---|---|---|---|
| | LAr trigger towers | | | Tile trigger towers | |
| | LAr large towers | | jFox | LAr trigger towers | jFEX |
| Had. calo. | Tile trigger towers | TileFox | | Tile trigger towers | |
| | Tile large towers | | gFox | LAr large towers | gFEX |
| | | | | Tile large towers | |
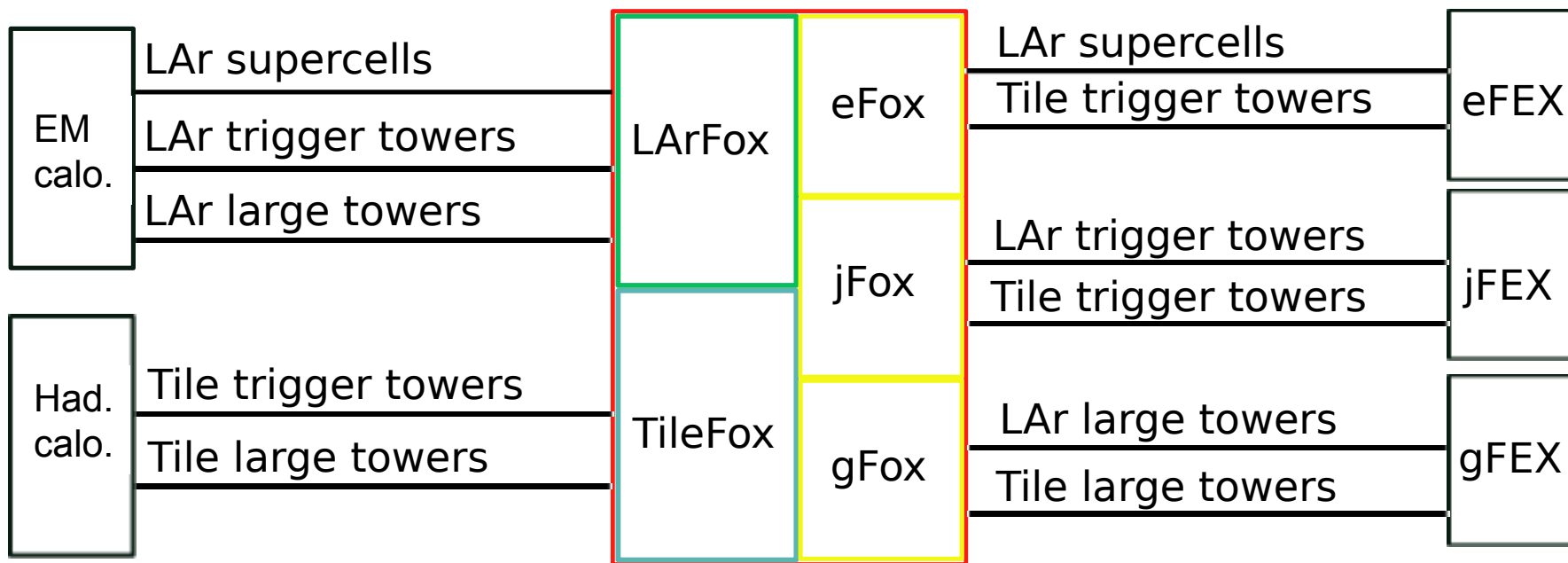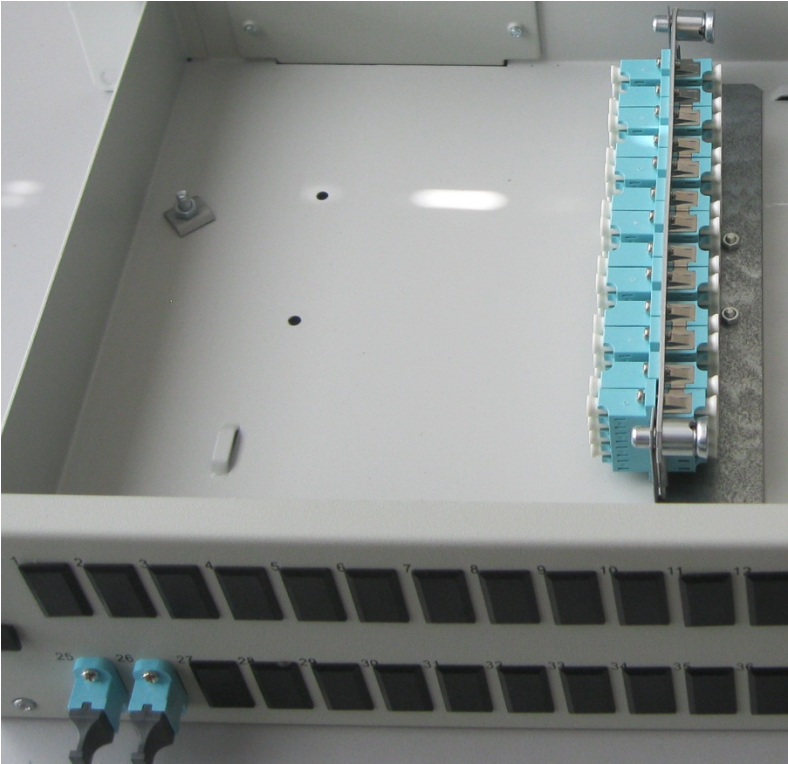
# 6.8.y.3: L1 Global Processing

- ## Deliverable is firmware that runs on the L1 Global Processor
  - The focus is on hadronic triggering with 4 related items
    - Offline-like "topological clustering" of calorimeter energy
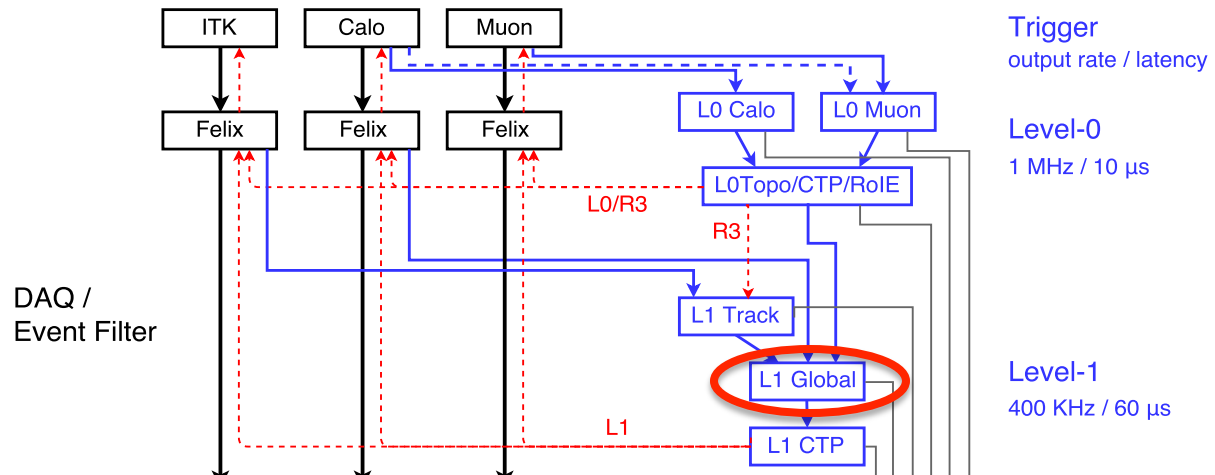    - Offline-like jet finding
    - Global quantities: Missing energy, sum of jet pTs (HT), and MHT
    - Track-based pile-up rejection for multijet and global quantities

- ## Follows Phase 1 experience with the gFEX system
  - gFEX is global quantities and fat-jets at what will be L0 in HL-LHC

# Ongoing R&D Efforts

- ## R&D Efforts underway using pre-MREFC funding

- ## 6.8.y.1: L0Calo Optical Plant
  - Phase-1 L1Calo optical plant R&D effort eliminates need for dedicated Phase-2 R&D effort.
    - Highly similar design to be implemented by the same PI/engineers

- ## 6.8.y.3: L1Global Algorithms
  - Current experiences with Phase-1 gFEX algorithm development useful
    - Studies of global quantities, jet substructure, large-R jet pileup subtraction
  - Dedicated R&D studies of topological clustering algorithms underway
    - Characterizing clustering algorithm limitations on FPGA targets
    - Latency/resource/resolution studies help guide hardware and algorithm choices
    - Same engineers expected to contribute to Phase-2 efforts

# Budget Estimation

- ## WBS 6.8.y.1: L0Calo Optical Plant
    - Primarily based on current Phase-1 Fiber Optic Exchange module
    - Well-understood technical scope and costs
    - Phase-1 experiences will reduce overall risk to both schedule and cost

- ## WBS 6.8.y.3: L1Global Firmware Algorithms
    - Based on current Phase-1 gFEX algorithm development
        - Highly similar to other ongoing or completed projects as well
        - ( L1Calo gFEX module: Global Feature Extractor )
    - Similar level of complexity and schedule demands
    - Expert-level estimation for anticipated differences wrt gFEX

- L0Calo Optical Plant costing developed via direct analogy to the ongoing Phase-1 optical plant project

### 6.8.x.1 L0Calo

| WBS | Description | Labor FTE | Labor Ayk$ | M&S Ayk$ | Travel Ayk$ | TOTAL Ayk$ |
|---|---|---|---|---|---|---|
| 6.8.x.1 | L0Calo | 0.75 | 119 | 49 | 19 | 187 |
| | Engineers | 0.75 | | | | |
| | Techs | - | | | | |
| | Students | - | | | | |
| | | - | | | | |

| Task Name | Effort (person-months) | Calendar Duration (months) |
|---|---|---|
| Engineering Specification | 1 | 6 |
| Design | 2 | 6 |
| Assembly | 1 | 9 |
| Acceptance Tests | 2 | 9 |
| System Tests | 2 | 6 |
| Project Review Preparation | 1 | 12 |
| | | |
| Project Total: | 9 (0.75 FTE) | 36 (total duration) |

| Item | Cost per item | # of items | Total cost |
|---|---|---|---|
| MTP cable | $150 | 120 | $18,000 |
| MTP breakout cable | $100 | 12 | $1,200 |
| Mapping module | $5,500 | 5 | $27,500 |
| Enclosure | $1000 | 1 | $1,000 |
| Misc parts | | | $1,300 |
| Total | | | $49,000 |

# Cost Tables: L1Global

- L1Global costing based on effort required for similar firmware algorithms in the ongoing Phase 1 gFEX FW project
  - Labor divided amongst six universities

| 6.8.x.3 L1 Global Processing | | | | | | |
|---|---|---|---|---|---|---|
| **WBS** | **Description** | **Labor FTE** | **Labor Ayk$** | **M&S Ayk$** | **Travel Ayk$** | **TOTAL Ayk$** |
| 6.8.x.3 | **L1 Global** | 8.75 | 1,896 | 125 | 82 | 2,103 |
| | Engineers | 8.75 | | | | |
| | Techs | - | | | | |
| | Students | - | | | | |
| | | | | | | |

# Cost Tables: WBS 6.8 Trigger

## 6.8 Trigger NSF FTEs

| Item/Phase | FY20 | FY21 | FY22 | FY23 | FY24 | Grand Total |
|---|---|---|---|---|---|---|
| **6.8.y.1 L0 Calo** | **-** | **0.25** | **0.42** | **0.08** | **-** | **0.75** |
| Design | - | 0.25 | - | - | - | 0.25 |
| Prototype | - | - | - | - | - | - |
| Pre-production | - | - | - | - | - | - |
| Production | - | - | 0.42 | 0.08 | - | 0.50 |
| **6.8.y.3 L1 Global Processing** | **1.25** | **2.50** | **2.50** | **2.50** | **-** | **8.75** |
| Design | - | - | - | - | - | - |
| Prototype | 1.25 | - | - | - | - | 1.25 |
| Pre-production | - | 2.50 | - | - | - | 2.50 |
| Production | - | - | 2.50 | 2.50 | - | 5.00 |
| **NSF Grand Total** | **1.25** | **2.75** | **2.92** | **2.58** | **-** | **9.50** |

## 6.8 Trigger NSF Total Cost (AYk$)

| Item/Phase | FY20 | FY21 | FY22 | FY23 | FY24 | Total |
|---|---|---|---|---|---|---|
| **6.8.y.1 L0 Calo** | **0** | **43** | **126** | **19** | **0** | **187** |
| Design | 0 | 43 | 0 | 0 | 0 | 43 |
| Prototype | 0 | 0 | 0 | 0 | 0 | 0 |
| Pre-production | 0 | 0 | 0 | 0 | 0 | 0 |
| Production | 0 | 0 | 126 | 19 | 0 | 144 |
| **6.8.y.3 L1 Global Processing** | **337** | **611** | **569** | **586** | **0** | **2,103** |
| Design | 0 | 0 | 0 | 0 | 0 | 0 |
| Prototype | 337 | 0 | 0 | 0 | 0 | 337 |
| Pre-production | 0 | 611 | 0 | 0 | 0 | 611 |
| Production | 0 | 0 | 569 | 586 | 0 | 1,155 |
| **NSF Grand Total** | **337** | **653** | **695** | **605** | **0** | **2,290** |

# Risks

- **General sources of risk**
    - Changes/delays in system requirements or sub-system interfaces L0Calo Primary Risks:
        - Delays in finalizing up/downstream interfaces: specifically new TileCal interface
        - Late changes in specification: # links, optical splitting, etc
    - L1Global Primary Risks:
        - Performance of available FPGAs or other processors different than expected
        - Trigger performance requirements evolve late in development cycle

- **Mitigation**
    - Schedules are designed to absorb moderate delays
        - Development can proceed in areas not impacted by final specifications
        - In extreme cases, moderate additional effort can be added
    - Performance issues can be handled by reducing target efficiencies if necessary
        - Ongoing R&D efforts front-load engineering experience with hardware
        - Algorithm performance expected to be adjustable to meet performance needs

# Closing Remarks

- ## US Deliverables
  - 6.8.y.1 L0 Calo fiber optic plant for new tile output
  - 6.8.y.3 L1 Global Processing algorithms for hadronic objects

- ## This package with have a high impact on the ability of ATLAS to maintain low threshold single lepton and hadronic triggers
  - Significant coherence of calorimeter trigger projects with US project as a whole in Phase-1 and HL-LHC upgrades

- ## Budget and Planning are based on Phase-1 experience
  - Ongoing Phase-1 optical plant and firmware efforts are highly similar in scope and complexity

# Backup